Implementation of TFT Inspection System Using The Stream Processor

Bum Yong Park , Chang Hee Lee, and PooGyeon Park

Electrical and Computer Engineering Division
Pohang University of Science and Technology Pohang, Kyungbuk, 790-784, Korea
(Tel : 82-54-279-5588; Fax : 82-54-279-2903)
(merongyong@postech.ac.kr, eooe@postech.ac.kr, ppg@postech.ac.kr)

Abstract: Recently, computational power of parallel processor is strong enough to be used in many applications. Following these trends, we adapted the stream processor for thin film transistor liquid crystal displays (TFT-LCD) inspection. In this paper, we explain various defects on TFT-LCD and describe the implementation of the inspection system on the stream processor and CPU respectively. The components and behavioral properties of the inspection system are also explained. Then, we compare the performance of the systems equipped with the stream processor and CPU using the inspection algorithm that utilizes the repeated characteristics of the TFT-LCD. It will be shown that this algorithm is easy to implement on the stream processor. Finally, the experiment results show the successful transition from the traditional CPU-based system to the stream processor based system in the TFT-LCD inspection.

Keywords: Thin Film Transistor (TFT), Inspection System, Stream Processor, Parallel Processing, Liquid Crystal Displays (LCD)

I. INTRODUCTION

The TFT-LCD is widely used in many electronic devices. As its manufacturing industry requires faster production speed with higher yield, a more accurate and faster inspection instrument is crucial. Since early 1990's, practical LCD inspection methods have been proposed [1]. Most of the early methods require physical contact on LCD panel, which results in slow inspection speed and complex production line. Recently, many inspection systems begin to use digital images captured by the charge coupled devices (CCD) or the complementary metal oxide semiconductor (CMOS) devices. Since these devices make non-contact inspection system possible, a fast and efficient inspection has been expected to be realized. However, the higher resolution and faster inspection speed, the huge amount of data needs to be processed.

The TFT-LCD has repeated patterns around the whole panel. Therefore, the inspection algorithms can utilize its repeated pattern [2]. Simple computation is repeated through the inspection, processing a huge amount of data. However, traditional serial processing using the central processing unit (CPU) is very inefficient for this application. As a solution of realizing the parallel processing, digital signal processors (DSP), application specific integrated circuits (ASIC) or field-programmable gate array (FPGA) connected in parallel have been solutions in the embedded system at extremely high costs. Moreover, their solutions have difficulties in modifying the algorithm.

In this paper, we adapt the stream processor of Stream Processor Inc. (SPI) against the previous solutions because of the parallel architecture inside a single chip and high programmability with C-like programming langue, called StreamC, at an affordable cost. The stream programming model exposes the parallelism and locality inherence in the application, and the SPI processor design and software development tools can easily exploit this parallelism and locality in hardware. Because of these advantages, it is possible to use it in many applications. The vision inspection is a good example of performance enhancement.

The paper is organized as follows. Section II explains defects on various TFT-LCD. Section III represents the algorithm used for the inspection and the performance comparisons. Section IV explains the implementation of the inspection systems on a stream processor. Section V shows simulation results and the improvement of the inspection speed of the system based on stream processor. Finally, section VI is conclusion.

II. DEFFECTS ON TFT-LCD

Defects on the TFT-LCD cause visual failure and electrical failure. Visual failure on TFT-LCD is classified into two parts: macro and micro-defects [3]. Macro-defects include "MURA", "SIMI" and "ZURE". "MURA" means unevenness of color. "SIMI" means a clack on TFT-LCD. ZURA means misalignment of TFT-LCD. They are generally large size and can be detected human's eye. Micro-defects include scratches, fingerprints, particles and pinholes. They are very small size and can be hardly found human's eye.

The proposed method in this paper focuses on macro-defects. Although macro-defects are large size, some defects cannot be founded by the visual system of human. Human inspector slows down the processing speed. So, as mentioned before, we used vision inspection system.

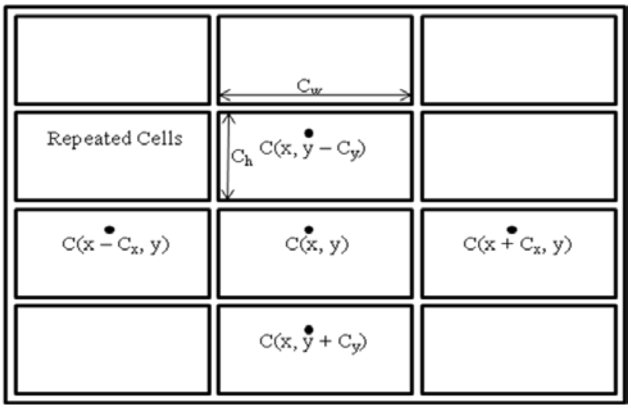

Fig.1. Repeated cells and variables on TFT-LCD

III. INSPECTION ALGORITHM

The following equations describe the basic decision scheme [4]. Fig. 1 shows repeated pattern on TFT-LCD and variables used in this algorithm. One pixel has a value of image data of 8 bit. The main equations of proposed algorithm are the followings.

$$D_U(x,y) = \begin{cases} |c(x,y) - c(x, y - C_h)| & if\ y > C_h, \\ |c(x,y) - c(x, y + 2C_h)| & if\ y < C_h, \end{cases} \quad (1)$$

$$D_D(x,y) = \begin{cases} |c(x,y) - c(x, y + C_h)| & if\ y < H - C_h, \\ |c(x,y) - c(x, y - 2C_h)| & if\ y > H - C_h, \end{cases} \quad (2)$$

$$D_L(x,y) = \begin{cases} |c(x,y) - c(x - C_x, y)| & if\ x > C_w, \\ |c(x,y) - c(x + 2C_x, y)| & if\ x < C_w, \end{cases} \quad (3)$$

$$D_R(x,y) = \begin{cases} |c(x,y) - c(x + C_x, y)| & if\ x < W - C_w, \\ |c(x,y) - c(x - 2C_x, y)| & if\ x > W - C_w, \end{cases} \quad (4)$$

$$O(x,y) = \begin{cases} 0 & if\ \min(D_U, D_D) \le T, \\ 1 & if\ \min(D_U, D_D) \ge T, \end{cases} \quad (5)$$

$$O(x,y) = \begin{cases} 0 & if\ \min(D_R, D_L) \le T, \\ 1 & if\ \min(D_R, D_L) \ge T, \end{cases} \quad (6)$$

$$O(x,y) = \begin{cases} 0 & if\ \min(D_U, D_D, D_R, D_L) \le T, \\ 1 & if\ \min(D_U, D_D, D_R, D_L) \ge T, \end{cases} \quad (7)$$

$$T = \begin{cases} T_L & if\ c(x,y) \le S \\ T_H & if\ c(x,y) > S \end{cases} \quad (8)$$

where

a) W is positive integer value of horizontal width.
b) H is positive integer value of vertical height.
c) c(x,y) is integer value of intensity at position (x,y) ranging from 0 to 255.
d) C_w is constant integer of horizontal length of repeated cell patterns.
e) C_h is constant integer of vertical length of repeated cell patterns.
f) $D_U(x,y)$, $D_D(x,y)$, $D_L(x,y)$ and $D_R(x,y)$ are differences of values of pixels.
g) T is positive constant integer of threshold to decide whether the target pixel is defective or not.
h) O(x,y) is the inspection result of pixel at (x,y). The value 1 means defective pixel and 0 means normal pixel.
i) T is decided by S which is a standard of value of pixel.

These are three equations (5), (6) and (7) in output value, O(x,y). When horizontal width, W is not longer than three times of that of cell, $3C_w$, equation (5) is used. When vertical height, H is not longer than three times of that of cell, $3C_h$, equation (6) is used. Threshold, T differs by value of pixel. Since defects are represented to black, T should be small when the value of pixel is small.

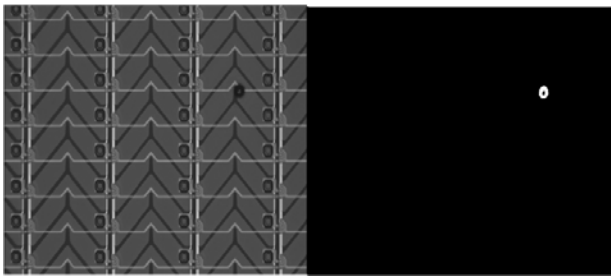

Fig.2. Tested image with defective pixels and resultant image.

IV. IMPLEMENTATION

The system consists of several CCD or CMOS sensors and stream processors. Most parts of the inspection algorithm run on the stream processor in a parallel manner.

A stream processor contains a general purpose unit (GPU) for data handling and control, a data parallel unit (DPU) for compute-intensive inner loop computations, and peripheral units that perform device i/o. The stream processor GPU contains two MIPS processors: System MIPS handles user interface and device i/o, while DSP MIPS handles communication with the DPU.

Implementation of algorithm on stream processor is simple. Input image data from CCD sensors are transferred to stream processor. One pixel line of image data is loaded to one lane which is process unit in DPU. Since the stream processor used this system have 16 lanes, once 16 pixel lines of image data are loaded to DPU. Values of pixels that loaded in DPU are calculated by DPU using the proposed algorithm.

V. RESULT

We used 2 different size of images, (1024, 720), (1024, 1000) $pixel^2$. Testing was done with previously acquired images. Fig. 2 shows one of tested images with the resolution (1024, 720) $pixel^2$ and has defective pixels to

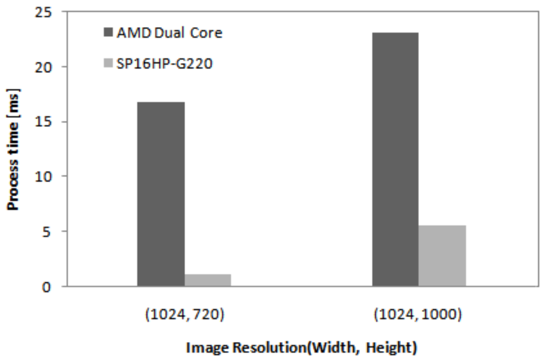

Fig.3. Comparison of the processing time by stream processor and CPU

show the inspection result more clearly. It is made by converting 0 to 255 and 1 to 0 from the results of equations (5) to visualize it.

Fig. 3 shows the comparison of processing speeds. Process time by stream processor contains the image data transmission from flash memory in system MIPS to memory in DPU. It shows superior speed enhancement of stream processor about 10 times better though it contains the transmission time. It also shows that processing time of a large image size is fast.

VI. CONCLUSION

We have presented implementation of a TFT-LCD inspection algorithm and its performance with stream processor and CPU. The TFT-LCD inspection algorithm is simple operation but it is applied to a huge size of data. So it requires parallel processing. Stream processor is one of the most proper devices that can increase processing speed. Also it is used for embedded system. The experimental results show how much its performance can be improved. As a future work, we consider that implementations of more sophisticate algorithm and the optimization of stream processor architectures.

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